Note on the Use of the Radiometer in Observing Small Gas Pressures; Application to the Detection of the Gaseous Products produced by Radio-active Bodies.

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(Received June 24,—Read June 27, 1907.)

Some time ago I exhibited at a soirée of the Royal Society a few experiments with the Crookes radiometer, the object being to show that when helium is the residuary gas filling the instrument, an attached charcoal condenser, even when placed in liquid hydrogen, is unable to diminish the pressure by absorption to such an extent that the radiometer will not rotate (when subjected to the concentrated beam of an electric arc lamp focussed upon the black surface of the mica vanes); while, on the other hand, if the gas instead of being helium is hydrogen, all radiometer motion is suspended. Even when the charcoal condenser of the helium radiometer was cooled in solid hydrogen under exhaustion so that a temperature of 15° absolute was reached, the rotation of the instrument was still very marked. If the radiometer is repeatedly washed out with the mixed oxygen and nitrogen got from the evaporation of liquid air, the charcoal and the whole of the glass being thoroughly heated and the apparatus finally exhausted to a fraction of a millimetre and sealed off, then, on placing the charcoal tube in liquid air, generally after an hour or two the vacuum is so high that no motion is induced by the beam of the electric arc. But if instead of liquid air the cooling agent is liquid hydrogen, then two minutes' immersion is sufficient to effect the same result, provided the radiometer is small and the gases get down a quill tube direct into the charcoal. Instead of the gases from liquid air being used to clean out the radiometer as described, it is for some purposes better to seal on a side tube containing perchlorate of potassium, which, when heated, gives pure oxygen. Further, in many experiments it is advantageous to exhaust the radiometer with its little charcoal condenser by means of a larger quantity of charcoal placed in liquid air for a night and then to seal the latter off before cooling the special charcoal bulb attached to the radiometer. When a McLeod gauge was sealed on to the end of the bulb containing the charcoal condenser which is cooled in liquid air (no stop-cocks of any kind being used), all the mercury vapour was eliminated from the radiometer, and the pressure of the permanent gas was found to be 0·00001 mm., or one seventy-six millionth of an atmosphere. In this condition the radiometer moved when the image of the poles was focussed on the black

vanes and after some 15 minutes' heating the pressure was found to be only one twenty-five millionth of an atmosphere and the pressure remained at this after 10 hours' cooling of the charcoal condenser in liquid air. The gas produced was no doubt hydrogen, got from the lamp black of the mica vanes, this being the first time the instrument was used. As a rule the radiometers require to be refilled, exhausted and tested more than once in order to get the motion reduced to a minimum. The importance of the removal of traces of gases like helium, hydrogen or neon is shown from the fact that a radiometer which has the charcoal removed from the attached bulb, and the latter cooled in liquid hydrogen (the instrument having been previously filled with dry air and exhausted to a fraction of a millimetre of mercury), will not reach such a vacuum as to stop the radiometer motion. Now, as the pressure of nitrogen at the boiling point of hydrogen must be of the order of a millionth of a millionth of an atmosphere, the action must come either from uncondensable gases, or the persistent adhesion of gas molecules to the glass and vanes of the radiometer or to some solid matter volatile under the conditions of the experiment. The lowest pressure reached in a charcoal vacuum after 10 minutes' cooling in solid hydrogen was still one hundred millionth of an atmosphere. The pressure observed is thus far too high and it may be that some of this is due to hydrogen coming from the charcoal. To get really high vacua by the charcoal method, even when liquid hydrogen is the cooling agent, it seems necessary to allow the absorption to go on for an hour or more, when the space to be exhausted is relatively large, and where narrow tubes or orifices constitute part of the apparatus, as in the McLeod gauge. Further, the presence of any organic matter on the vanes is fatal. No amount of cooling of the charcoal in liquid hydrogen of a radiometer filled as usual and tested in the ordinary manner, in which the vanes were made of pith, makes a vacuum sufficient to stop the radiometer motion. The concentrated beam, each time it was applied, was generating gas. In all the experiments the arc used was expending 10 ampères and the focus was adjusted to about 3 feet from the lamp. The radiometers had a volume of from 150 to 20 c.c.

Finding the McLeod gauge very difficult to use, a new method of defining the maximum limit of the working pressure (under the defined circumstances) depending upon the vapour-pressure of mercury was devised. For this purpose a side tube was sealed on to the top of the radiometer and this, after being bent twice at right angles, ended in a little bulb containing a globule of mercury. After the radiometer and charcoal were heated and exhausted and repeatedly washed out with the gas from liquid air, the charcoal was cooled in liquid air and the mercury allowed to

distil for an hour or two. After this treatment, on cooling the mercury with liquid air, the radiometer in a short time became inactive. In this condition the mercury was placed in an alcohol bath at $-80°$ C. and the temperature allowed to rise slowly.

In this way it was found the radiometer action began in the instrument used at $-23°$ C. The pressure of mercury vapour for the temperature derived from the Hertz formulæ is found to be about a fifty millionth of an atmosphere. All the time of the experiment the mercury vapour was being sucked out of the radiometer by the liquid air cooling of the charcoal tube, so that the pressure might be less than the saturated pressure. This result at once suggested that the method ought to be applicable to the detection of the gaseous products derived from the transformation of radio-active bodies. In order to test this application, a side tube containing a little radium bromide was sealed on to the bottom of the charcoal condenser, in order to remove the emanation by absorption in the charcoal kept in liquid air. The radiometer, after thorough washing with the gas from liquid air, heating and exhaustion by a subsidiary charcoal condenser placed in liquid air that was sealed off, was found inactive after the small charcoal receptacle was cooled for an hour in liquid air. The radiometer was again tested after standing 15 hours and was found to be quite active. It would seem that the gas produced must be hydrogen, helium, or the alpha particles. In order to eliminate any hydrogen that might be produced, the charcoal condenser of the radiometer was transferred from liquid air, in which it had been kept for some two days, into liquid hydrogen. After half an hour's cooling the motion was active when the image of the arc lamp was focussed on the black surface of the mica vanes of the radiometer, and even after one hour's immersion of the charcoal in the liquid hydrogen the motion suffered no diminution. The active gas must, therefore, have been helium along with it may be the alpha particles; unless one is being deceived by some solid deposited on the radiometer vanes sufficiently volatile when the arc light is concentrated on them to cause the motion. A similar radiometer to that which was used in the radium experiment had a side tube attached containing some 50 grammes of thoria, and after the usual treatment was found inactive. After keeping a fortnight it is now active, but I have not had the opportunity of cooling the charcoal in liquid hydrogen, so that the possibility of the gas being hydrogen has not been eliminated. We might anticipate that monadic gases of the type of helium and mercury would be more effective than the ordinary gases in inducing radiometer motion. A radiometer with a helium residue will still work under fixed conditions when the gas pressure is four or five times higher than one containing an oxygen residuum. Again, the sensibility of the

instrument ought to increase, provided it was subjected to the same intensity of radiation while immersed in liquid air or liquid hydrogen.

The experiments, in any case, seem to show that the radiometer may be used as an efficient instrument of research for the detection of small gas pressures and the study of radio-active products. For quantitative measurements the torsion balance or bifilar suspension must be employed. It would be interesting to repeat light repulsion experiments in the highest attainable charcoal vacuum. Later on I hope to extend the investigation.

Some Notes on Carbon at High Temperatures and Pressures.

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(Received June 20,—Read June 27, 1907.)

Following the subject of my paper of 1888 to this Society, which will be referred to in a subsequent communication, attempts have recently been made to melt carbon by electrical resistance heating under pressure, and the following is a short summary of the results of about 100 experiments.

The procedure has been on two lines. In the first, carbon is treated in bulk in a thick tube of 8 inches internal diameter of gun steel closed below by a massive pole of steel insulated from but gas tight with the mould and above by a closely fitting steel ram packed by copper rings imbedded in grooves in the ram or by leather and steel cups according to whether solids, liquids or gases are to be contained. The bore of the mould is generally lined with asbestos and after being charged the whole is placed under a 2000-ton press, the head and baseplate being insulated and connected to the terminals of a 300-kilowatt storage battery with coupling arrangements for 4, 8, 16 or 48 volts.

It was hoped that the greater thermal and electrical conductivity of steel as compared with carbon or graphite at moderate temperatures would with the help of water jackets keep the outer layers comparatively cool and that the increased conductivity of the central portions consequent on their higher temperature and conversion to graphite would so centralise the current on the core lying between the poles as to melt it.

Further concentration of current was obtained in the initial stages of heating by packing the central portion with carbon rods on end or by a compressed graphite core, and filling in around with coarsely broken arc-light carbon, or with wood charcoal (which is a bad conductor until highly heated).

With pressures of about 30 tons per square inch, and currents commencing